



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

NGUYEN Anh Tuan, PHAM Van Viet

Hanoi University of Mining and Geology, Vietnam

Email: nguyenanhluan@humg.edu.vn

Tel: 0912507096

Hanoi, 22/12/2023



Content

- **Introduction**
- **Discontinuities and suggested characterization methods**
- **Input and output parameters**
 - Uncertainties of input parameters
 - Uncertainties of output parameters
 - Orientation distribution
 - Spacing distribution
 - Trace length and fracture size
 - General network models
 - Distribution of unstable blocks
- **Automatic Mapping of Rock Mass Joints Using UAV Technology**
- **Case Study (in Vietnam)**
- **Conclusions**



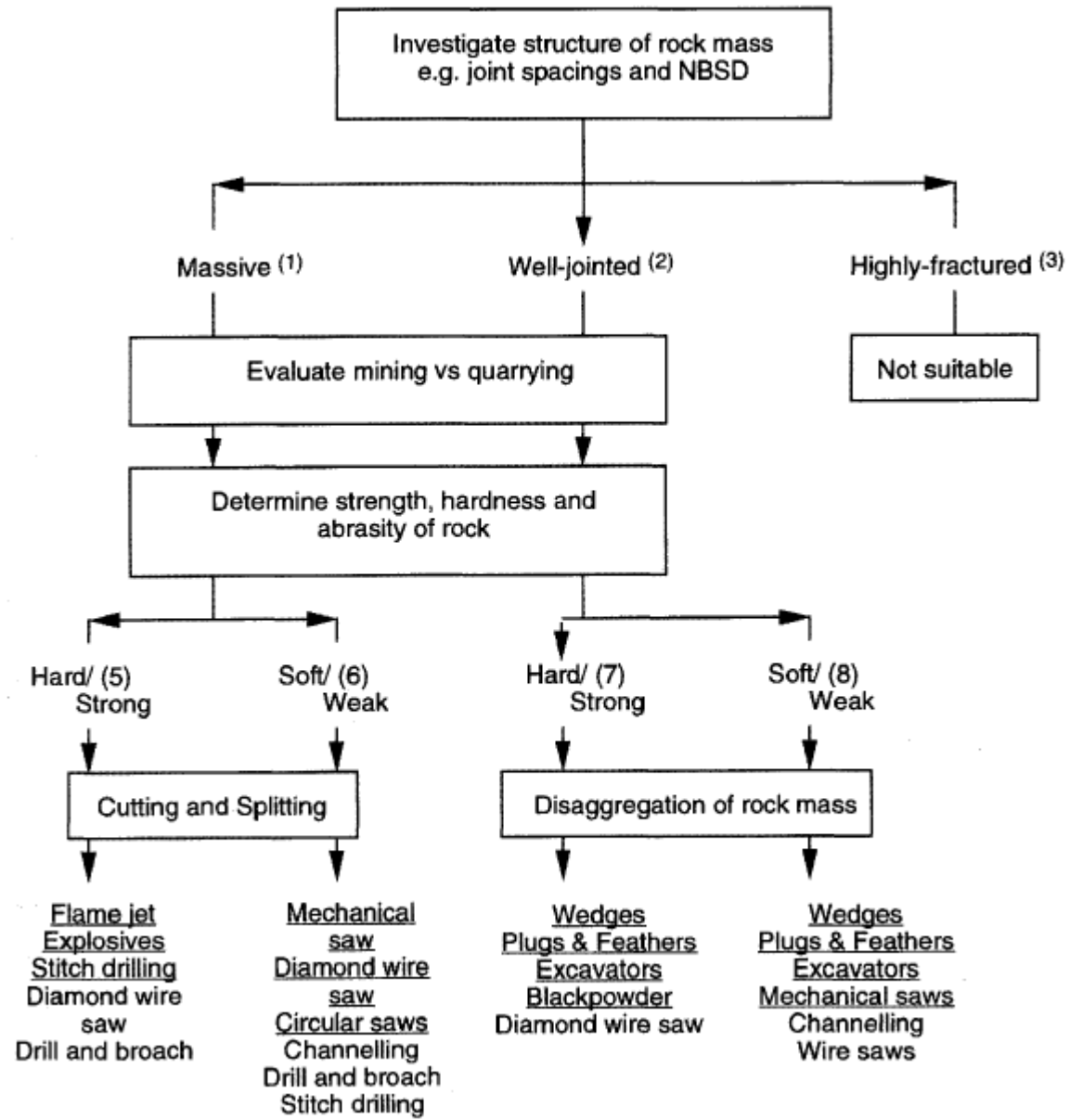
Introduction

- (1) Widely spaced joints, NBSD >> specification
- (2) Joint spacings and NBSD \geq specification
- (3) Joint spacings and NBSD << specification

- (5) As typified by many granites
- (6) As typified by many marbles
- (7) As typified by many sandstones and slates
- (8) As typified by many limestones

The Natural Block Size Distribution (NBSD)

Mining optimization to recover the maximum blocks



Stone Building Stone, Rock Fill and Armourstone in construction (M._R._Smith, p498, 1999)



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

The different types of Discontinuities/ Joints and suggested characterization methods

Table 1 Parameters used to characterize discontinuities and methods of data collection (1978 and current)

Parameter	Traditional method (International Society for Rock Mechanics 1978)	Current methods
1. Orientation	(A) Compass and clinometer method Compass and clinometer Clino-rule of 50 m (B) Photogrammetric method Reconnaissance survey equipment Phototheodolite and tripod Control survey equipment Stereoscopic plotting instrument	3D point clouds 3D laser scanning (Jaboyedoff et al. 2012; Riquelme et al. 2014) Digital stereo-photogrammetry (Haneberg 2008; Lato et al. 2012) SfM (Jordá Bordehore et al. 2017)
2. Spacing	Measuring tape, min 3 m Compass and clinometer	3D point clouds TLS and ALS (Slob et al. 2010; Oppikofer et al. 2011; Riquelme et al. 2015)
3. Persistence	Measuring tape, min 10 m	3D point clouds TLS (Sturzenegger and Stead 2009a; Oppikofer et al. 2011)
4. Roughness	(A) linear profiling method and JRC (Barton and Choubey 1977) Folding straight edge of at least 2 m, in mm Compass and clinometer 10 m of light wire, marks at 1 m (B) Compass and disc-clinometer method Clar geological compass Four thin circular plates (C) Photogrammetric method: same as (1)	3D point clouds (Rahman et al. 2006; Haneberg 2007; Oppikofer et al. 2009; Khoshelham et al. 2011; Lai et al. 2014) Photographs (Alameda 2014) Profiles (Tatone and Grasselli 2010)
5. Wall strength	Geological hammer with one tapered end Strong pen knife Schmidt hammer: JCS Facilities for measuring the dry density of the rock	
6. Aperture	Measuring tape of at least 3 m, graduated in mm Feeler gauge White spray paint Equipment for washing the exposed rock	Infill scale-independent classification (Ortega et al. 2006)
7. Filling	Measuring tape of at least 3 m, graduated in mm Folding straight -edge, at least 2 m Plastic bags for taking samples Geological hammer with one tapered end Strong pen knife	Hyperspectral imaging (Kurz et al. 2011)
8. Seepage	Visual observation Air photographs, weather records	TLS (Sturzenegger et al. 2007; Vivas et al. 2015) Photographs Digital Photogrammetry Thermal images (Vivas et al. 2015)
9. N of sets	Based on (1)	Based on (1)
10. Block size	Measuring tape of at least 3 m, graduated in mm	3D point clouds TLS (Sturzenegger et al. 2011) SfM (Ruiz-Carulla et al. 2017)

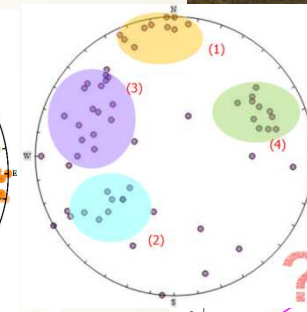
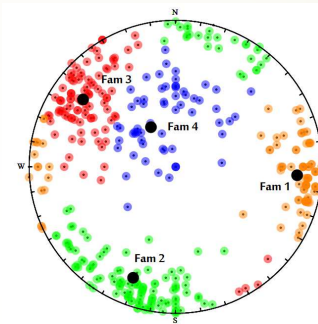


Automatic Mapping of Rock Mass Joints Using Laser Scanning Data: A Case Study

INPUT AND OUTPUT PARAMETERS

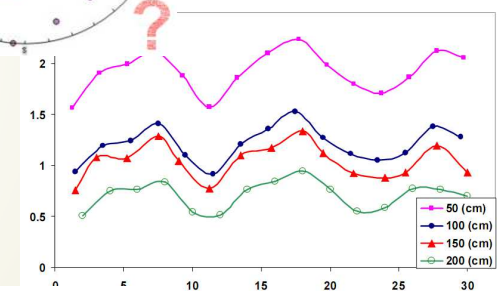
- Site presentation and field measurements
- To group discontinuities into main families, different methods of grouping them in sets can be used.

Uncertainties of input parameters



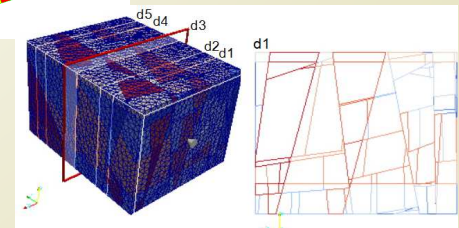
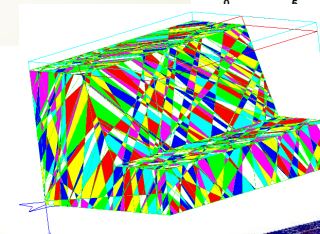
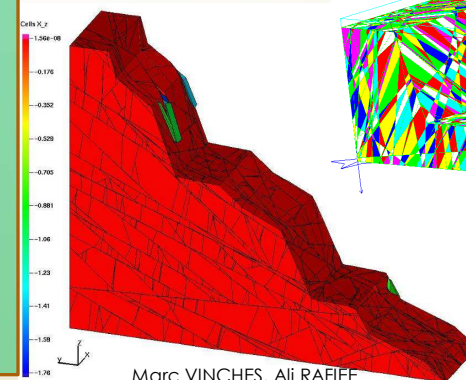
- Geostatistical analysis: define parameters of the statistical law of orientation and the statistical law of spacing and their parameters.

Uncertainties of output parameters



- 3D model of rock mass: simulations stochastiques with the RESOBLOK

- Results and Conclusion: analyze influence of the regrouping on instability parameters



Marc VINCHES, Ali RAFIEE

Uncertainties of input parameters

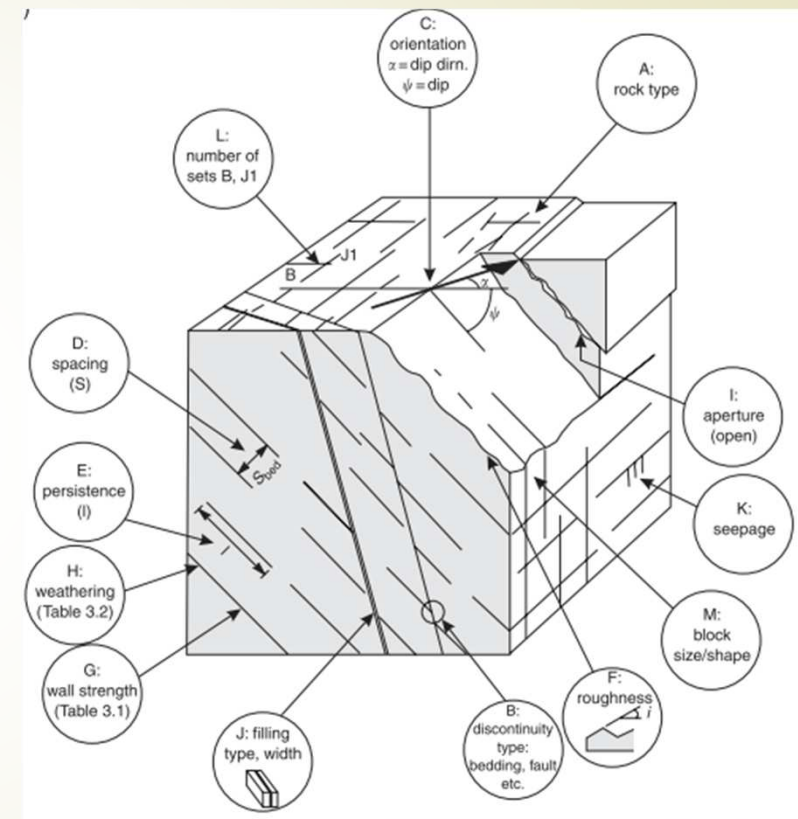
3 mains types of survey:

- borehole surveys,
- scanline surveys, and
- areal surveys.

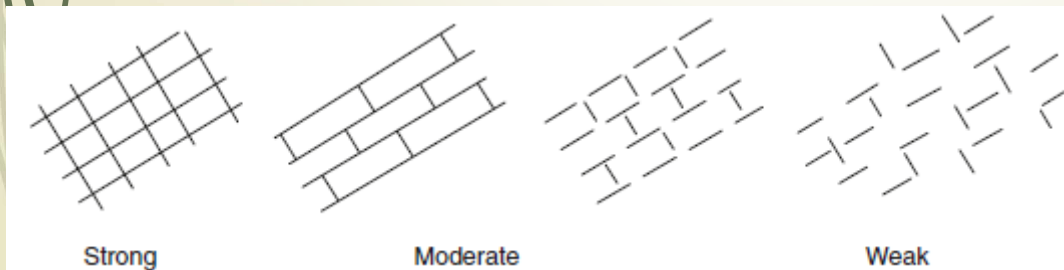
Input parameters such as:

- Discontinuities(fracture orientation, fracture density, spacing, trace length, fracture size, presence of fracture clusters, etc.)
- slope orientation,
- model dimensions of slope cuts,
- etc.

were considered as inputs parameters.



(Ducan C. Wyllie, 1999)

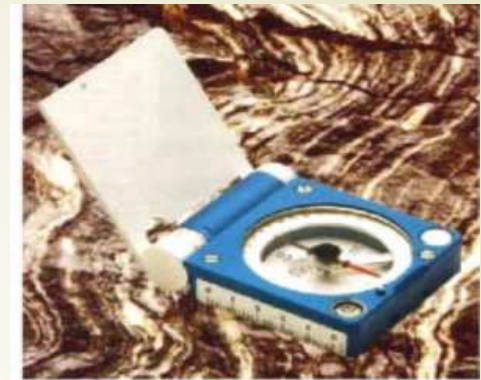
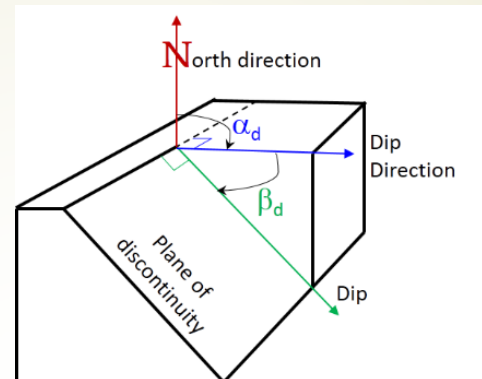
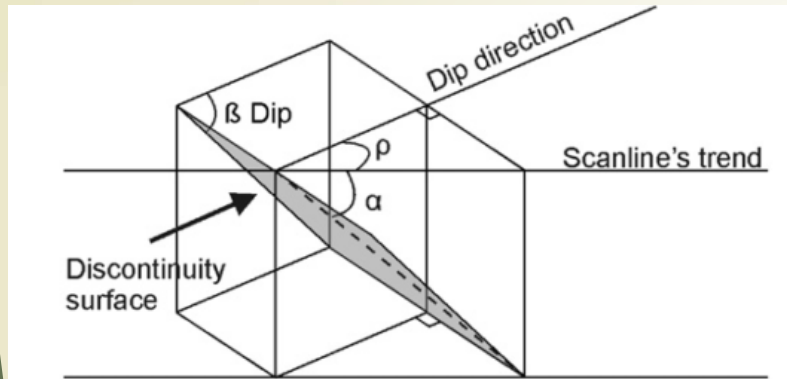


Influence of persistence of discontinuity on the degree of fracturing and interconnectivity

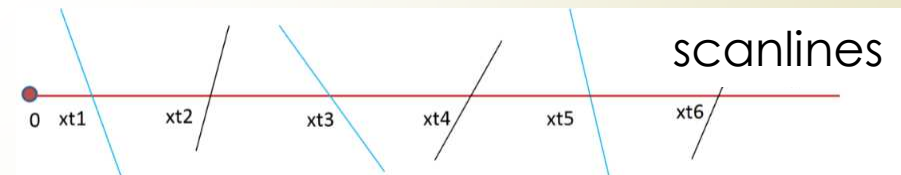
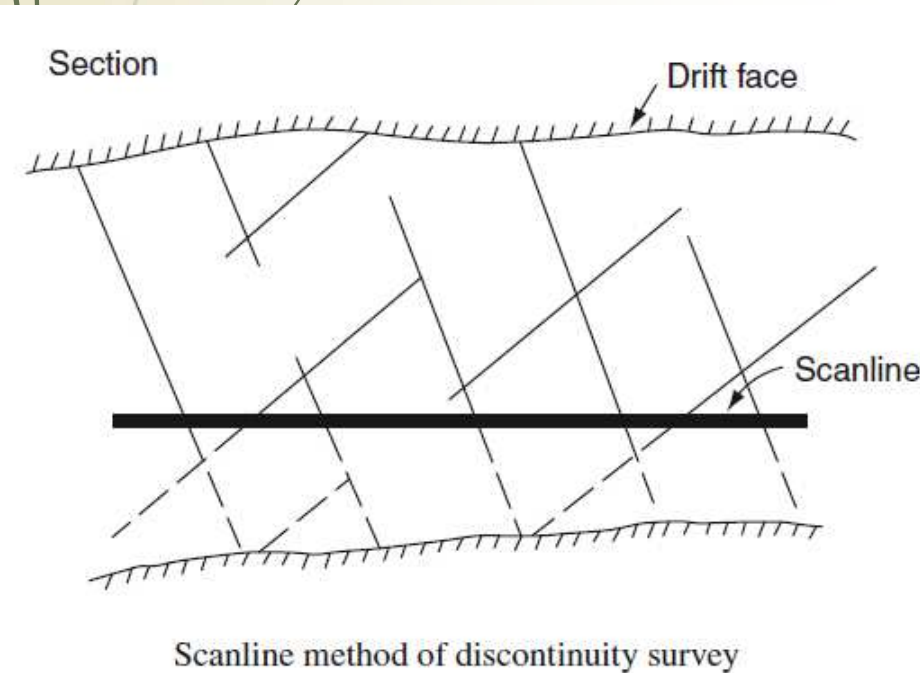


Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

The structural data



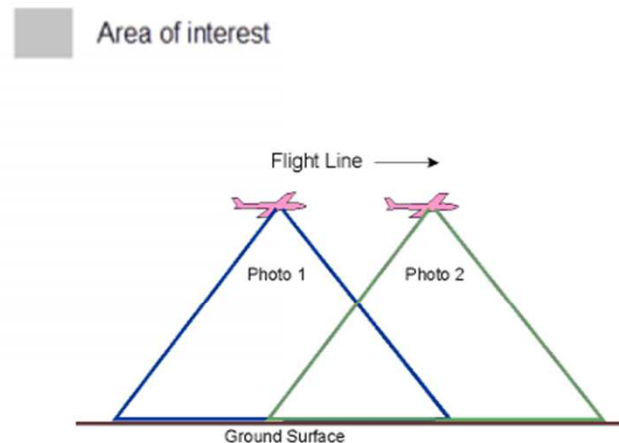
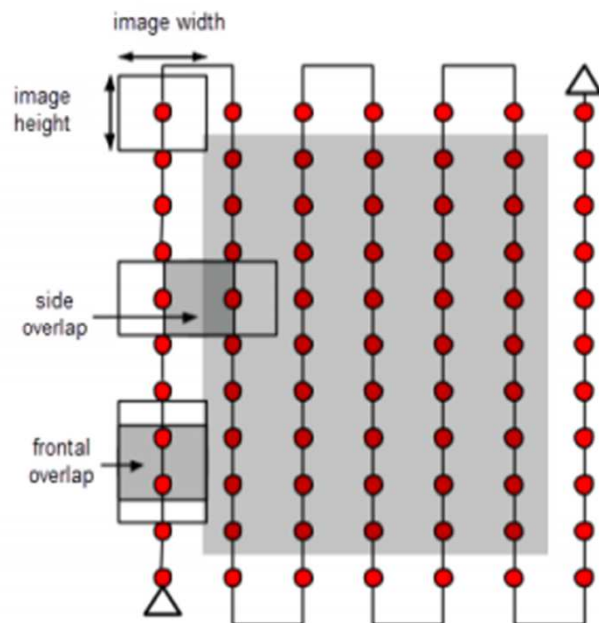
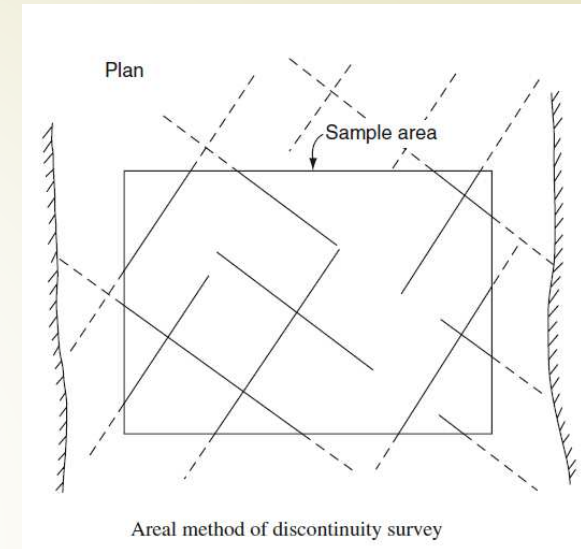
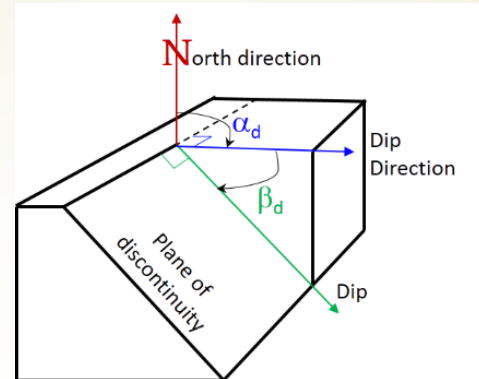
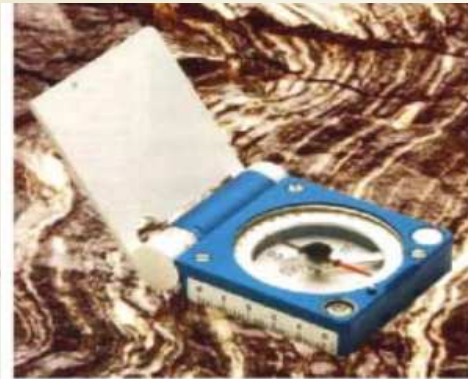
Field measurements, different stations, using scanlines





Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

The structural data



DJI Phantom 4 RTK



Leica Aibot SX RTK



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

The structural data

➤ The data of discontinuities and their parameters are usually acquired via: core logging, scan line, window mapping or other methods.

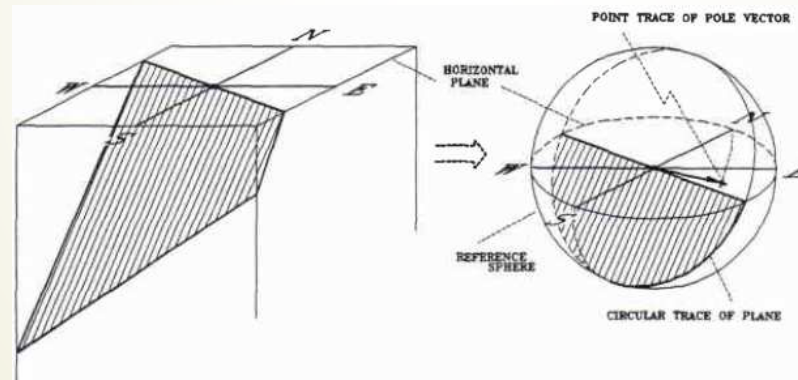
➤ Orientation of a discontinuity: dip angle (β_d), dip direction (α_d).

➤ The trend (α_n) and plunge (β_n):

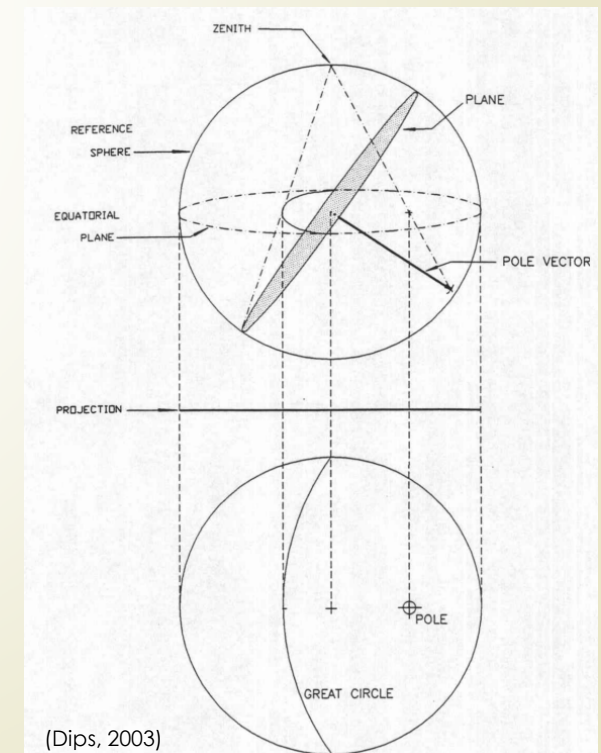
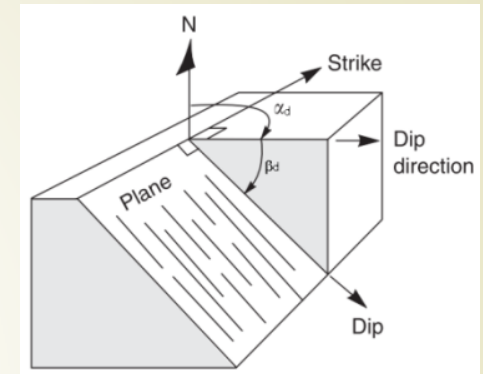
$$\alpha_n = \alpha_d \pm 180^\circ; (0^\circ \leq \alpha_n \leq 360^\circ) \text{ and } \beta_n = 90^\circ - \beta_d$$

➤ The normal of a plane by a unit vector $X^T(u_x, u_y, u_z)$ in a Cartesian coordinate system:

$$\begin{cases} u_x = \cos(\alpha_n) \cos(\beta_n) \\ u_y = \sin(\alpha_n) \cos(\beta_n) \\ u_z = \sin(\beta_n) \end{cases}$$



(Dips, 2003)



(Dips, 2003)

We used lower hemisphere Schmidt net to represent the orientation data in this paper.



Uncertainties of input parameters:

The grouping of discontinuities into main families (with different methods):

- Schmidt (1925), Kamb (1959) and Priest (1993) => isodensity curves of poles in stereographic net.
 - Mahtab, Yegulalp and Shanley (1976, 1982) => counting techniques and sought to minimize an objective function.
 - Harrison (1992) and Hammah Curran (1998, 1999, 2000) => the algorithm of fuzzy k-mean.
 - Klose and al. (2005) => the vector quantification, directional data are grouped into separate isotropic clusters and at the same time the average dip direction and dip angle are calculated for each group.
 - Andrew, Michael and Weiss (2002) ; Jimenez-Rodrigueza and al. (2007) => the spectral clustering approach with a simple measure of similarity between normal unit vectors in the spherical space. Spectral clustering algorithms group points using eigenvectors of matrices from the orientation data, etc.
- Numerous cases, the number of families is defined in advance, while the decision is subjective and can depend on " the operator ".
- We propose here the algorithms of following grouping:

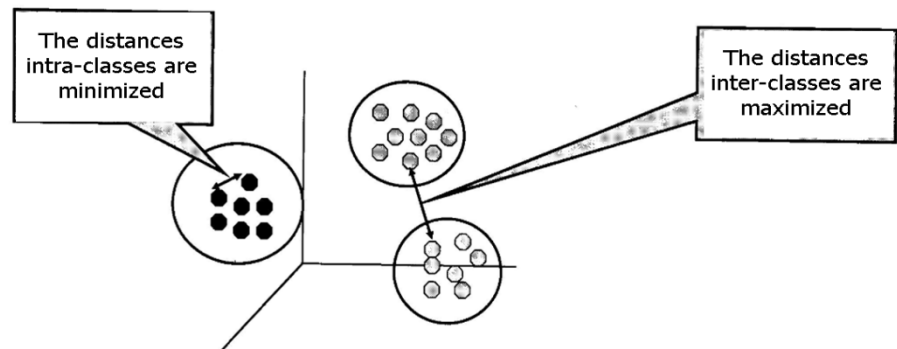
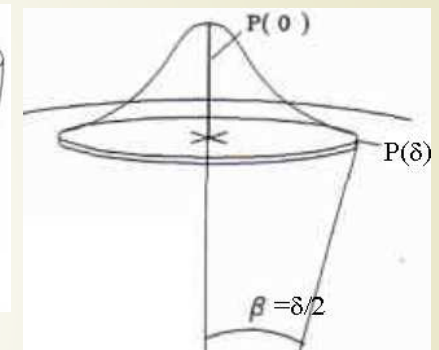
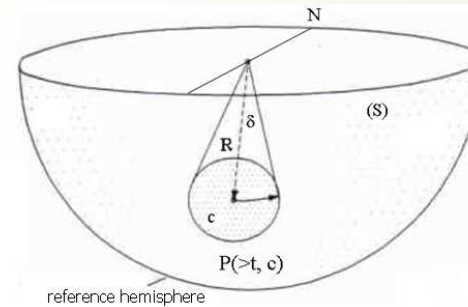
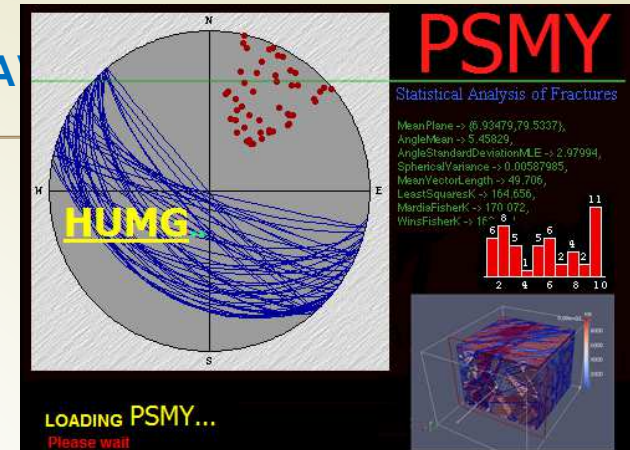
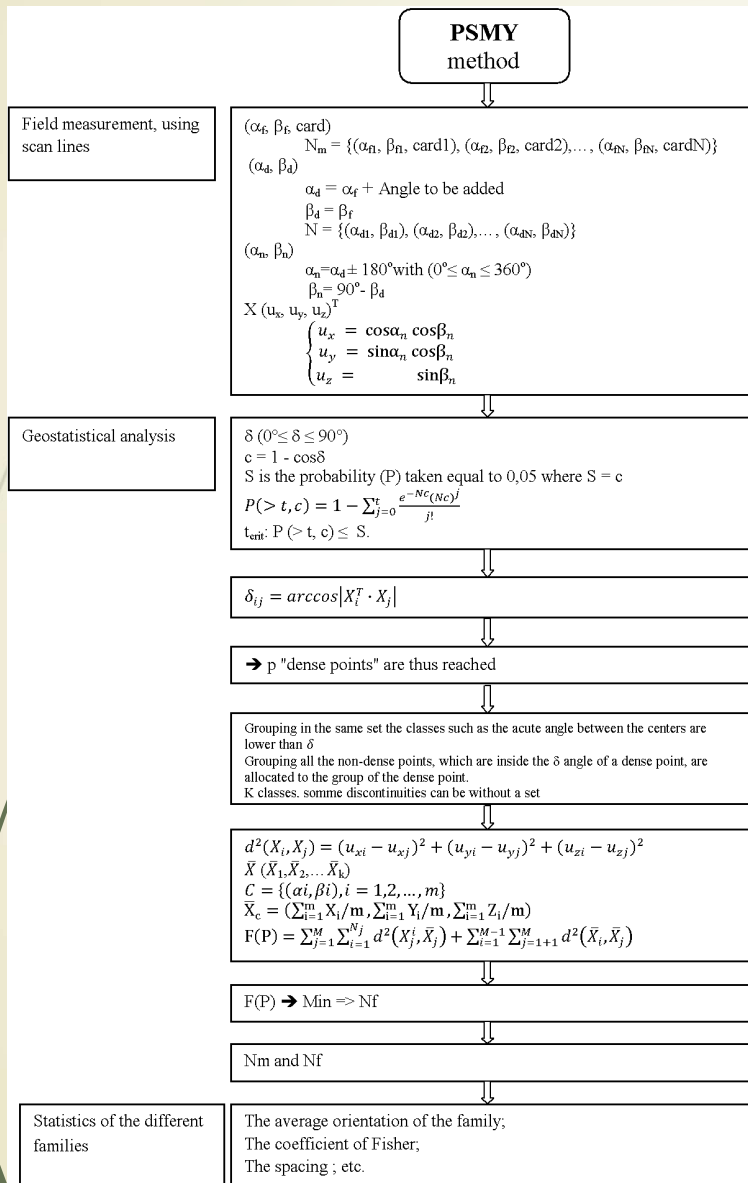
1. Grouping "automatically", method was named PSMY because it combines and develops S.Priest (1993); Shanley and Mahtab (1976) Mahtab and Yegulalp (1982): PSMY (Nguyen2014)

2. Grouping "automatique" into K families (K of the PSMY method) with a spectral method of grouping (Andrew, Michael, & Weiss, 2002; Jimenez-Rodriguez & Sitar, 2007).

3. Using Dips software of RockScience (2003): it is possible to group the discontinuities in the main family around the zones of high density of fracture and the boundaries of the groups are chosen by the user of the software.



Automatic Mapping of Rock Mass Joints Using UA

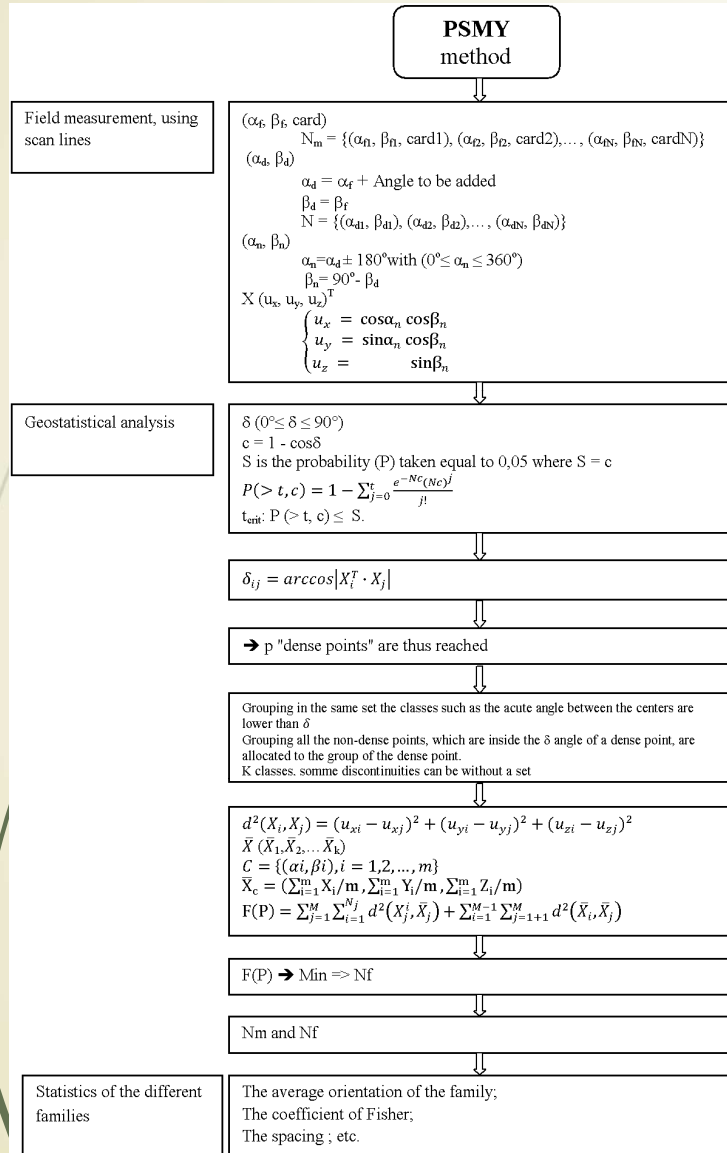


An « objective function » based on the Huygens (Picard, 1999) decomposition as suggested by Shanley RJ, Mahtab MA (1976)

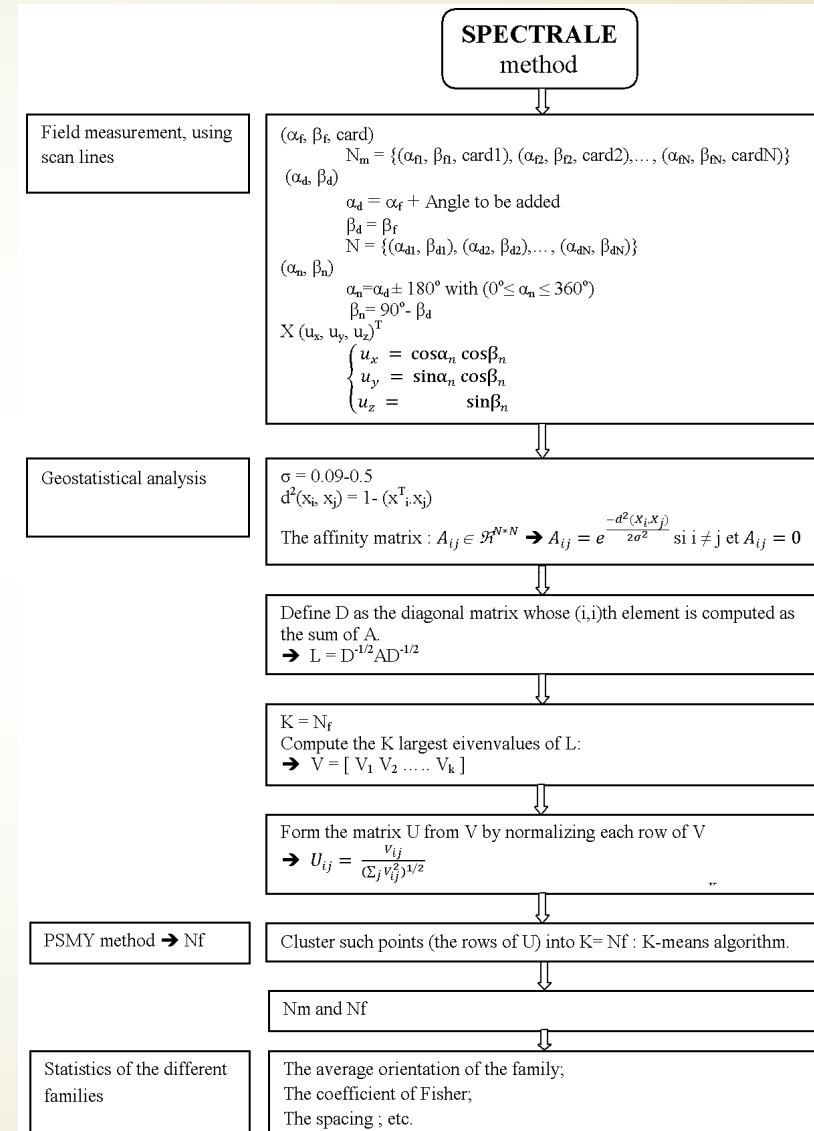
Flowchart of PSMY method grouping



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study



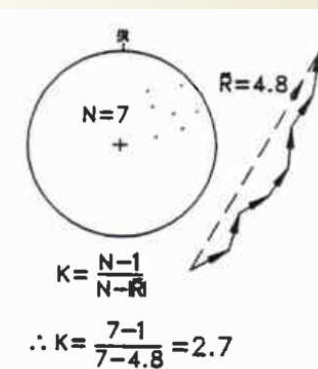
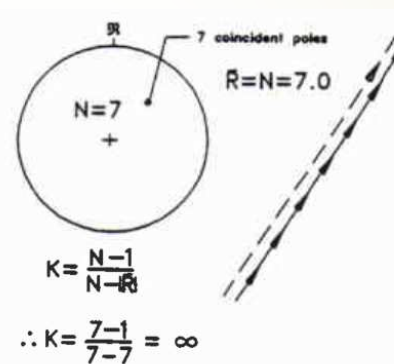
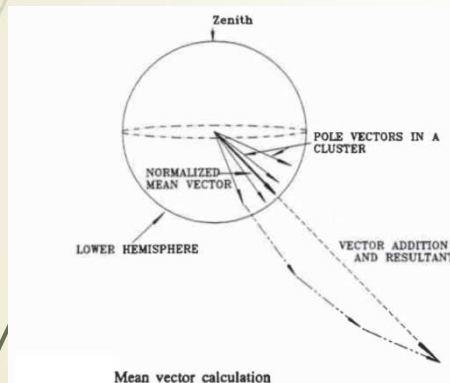
Flowchart of PSMY method grouping



Flowchart of SPECTRAL method grouping

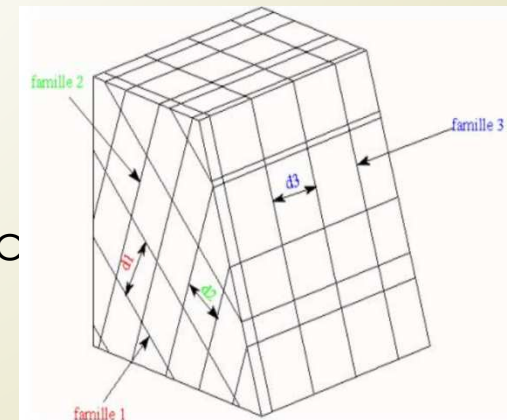
Statistics of the different families

- ▶ The statistics of orientation of fractures was detailed by Peaker (1990) and Priest (1993) or Hammah & Curran (1998) => the same value
- ▶ The distribution of the poles according to a given direction is usually adjusted by Fisher distribution via the coefficient of Fisher (K).



Peaker (1990)

- ▶ Discontinuity spacing can then be calculated within each discontinuity set, and is generally fitted to negative exponential, log-normal or gamma, etc depending on their mean (m) and standard deviation (σ).





ORIENTATION DISTRIBUTION

If the directions are uniformly distributed on the upper hemisphere, the probability density function (pdf) associated with a surface element ds is $ds / (2\pi)$. Expressed in spherical coordinates as the surface associated with $d\theta$ and $d\phi$ is $ds = \sin\theta \, d\theta \, d\phi$, the bivariate pdf of the polar coordinates θ, ϕ referred to the reference sphere is expressed by uniform distribution, such as:

$$f(\theta, \phi) = \frac{1}{2\pi} \sin\theta \quad 0 < \theta < \pi/2 \quad 0 < \phi < 2\pi \quad (1)$$

with θ (dip angle), ϕ (2π - strike azimuth) are independently distributed, ϕ is uniformly distributed on $[0, 2\pi]$, and $\cos\theta$ uniformly distributed on $[0, 1]$.

Fisher distribution is an isotropic nonuniform distribution, the pdf of the polar coordinates (θ', ϕ') referred to the reference sphere is:

$$f(\theta', \phi') = \frac{1}{2\pi} \frac{k \sin\theta'}{e^k - e^{-k}} \exp(k \cos\theta') \quad 0 < \theta' < \pi \quad 0 < \phi' < 2\pi \quad (2)$$

With k is a concentration parameter: for $k = 0$, the mass is uniformly distributed; for large k , the mass is concentrated on a small portion of the sphere around the pole of the mean direction. It can be estimated k and used to check whether the bivariate distribution of (θ, ϕ) such as truncated Fisher.



SPACING DISTRIBUTION

The intersection of any of the basic models with a line provides a 1D Poisson process (Priest 1993). Successive spacing is independent and follow an exponential distribution.

$$P(k, x) = \frac{e^{-\lambda x} (\lambda x)^k}{k!} \quad (3)$$

If the total event discontinuity frequency is λ , can be shown that the probability $P(k, x)$ of exactly k events (discontinuity intersections) occurring in an interval of length x , selected at random along the line (Scanline surveys). The probability of zero events in an interval is found by setting $k=0$, giving $P(0, x) = e^{-\lambda x}$.

TRACE LENGTH AND FRACTURE SIZE

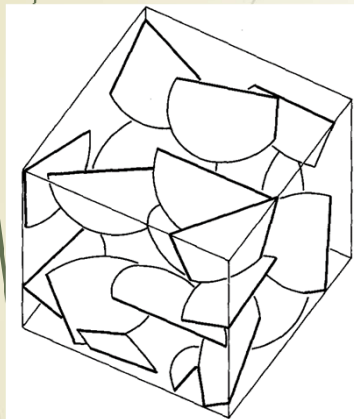
If fractures cannot be considered as infinite at the scale of the study, the distribution of their size largely determines the frequency of intersection and hence the mechanical behavior of the rock mass. In practice, it is not possible to observe the exact size of a fracture. A 2D survey, however, provides the trace length distribution, which linked with the fracture size distribution. But the experimental histogram of trace length is affected by several biases that have to be corrected. For a fixed 3D fracturation density, there is a better connectivity with a few large fractures than with many small ones.



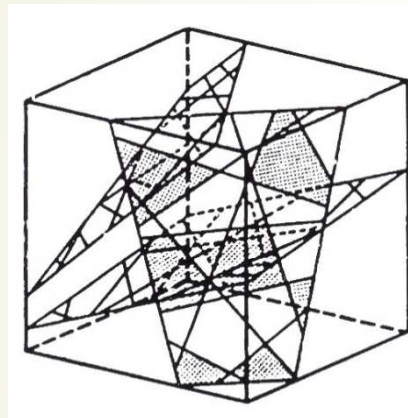
Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

NETWORK MODELS

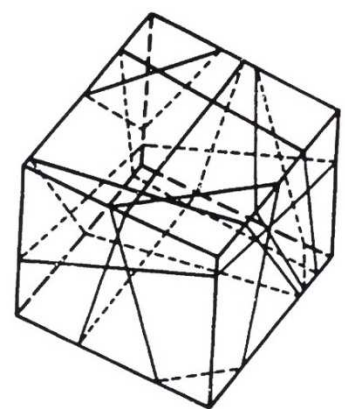
Baecher (1978)



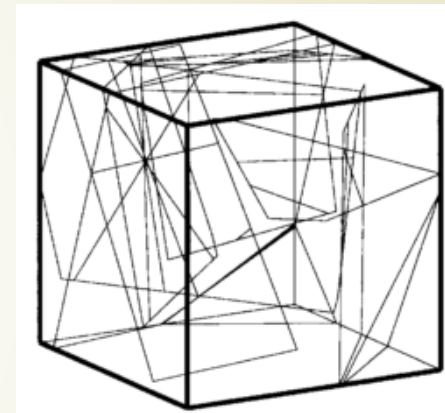
Veneziano (1978)



Dershowitz (1978)



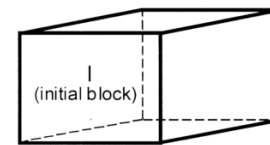
Combination: (Lin et al. 1987; Jing 2000; Lu 2002)



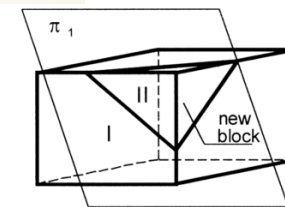
DFN models: Warburton (1983), Heliot (1988), (Jing 2000, 2003)



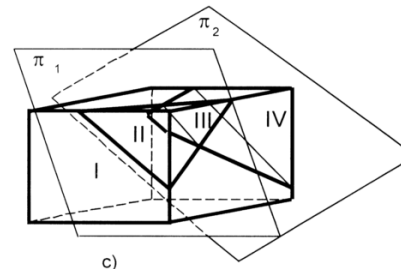
RESOBLOK (Heliot 1988)



a)



b)



c)

π_i — discontinuity planes
I, II, III — block numbers

(Jing, 2000).



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

1) Fracture Measurements
(orientation, spacing, length, fracture ends ...)

determinist measurement (pilot site)/
scanline measurement (prediction)



2) Fracture Analysis (DIPS, STAF, PSMY)
(family of orientations, fractures organisation rules,
adjustment of fracture parameters to statistical laws)



3) Representation of the fractured rockmass
(RESOBLOK, LMGC90)

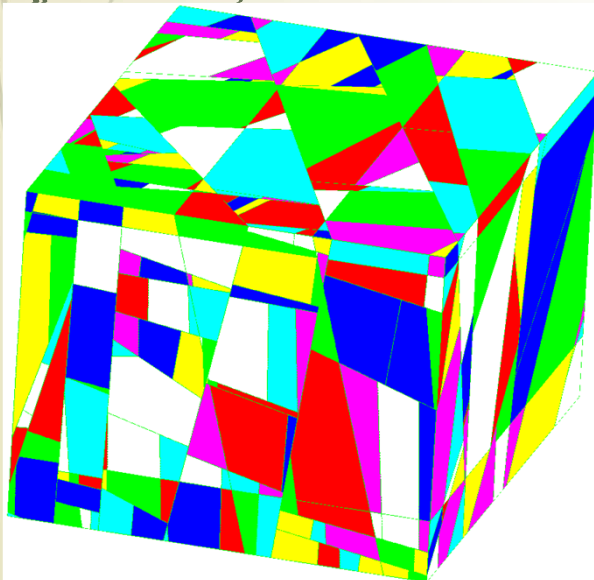
determinist simulation (validation) /
stochastic simulation (prediction)

standart version (hierachic rules) /
new version (+ fracture length)

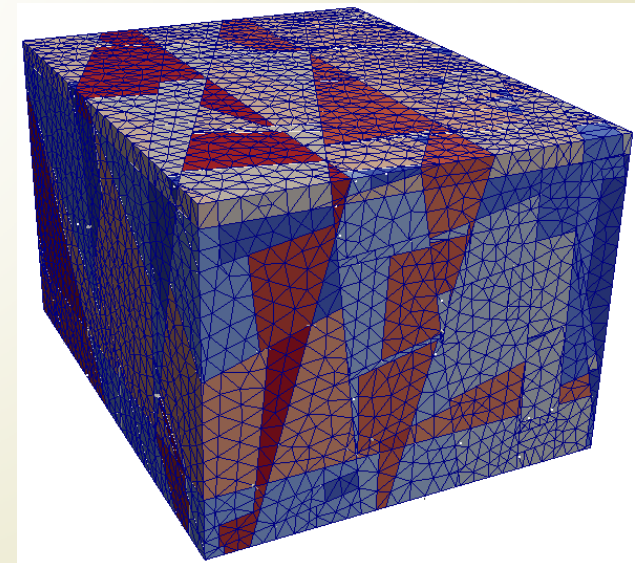


Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

RESOBLOK was developed by LAEGO and INERIS, Ecoles des Mines de Nancy. Heliot (1988), Asof(1991), Baroudi (1992), Korini (1995), Merrien-Shoukatchoff and al. (2012), Nguyen A.T and al. (2014, 2015). RESOBLOK is a discrete fracture network (DFN) code which couples geometrical block system construction and an iterative stability analysis based on limit equilibrium stability analysis according a vector analysis method initially proposed by Warburton (1981). From statistical knowledge on fracture orientation and spacing, block geometries can be computed according the statistic, then a stability analysis is run.

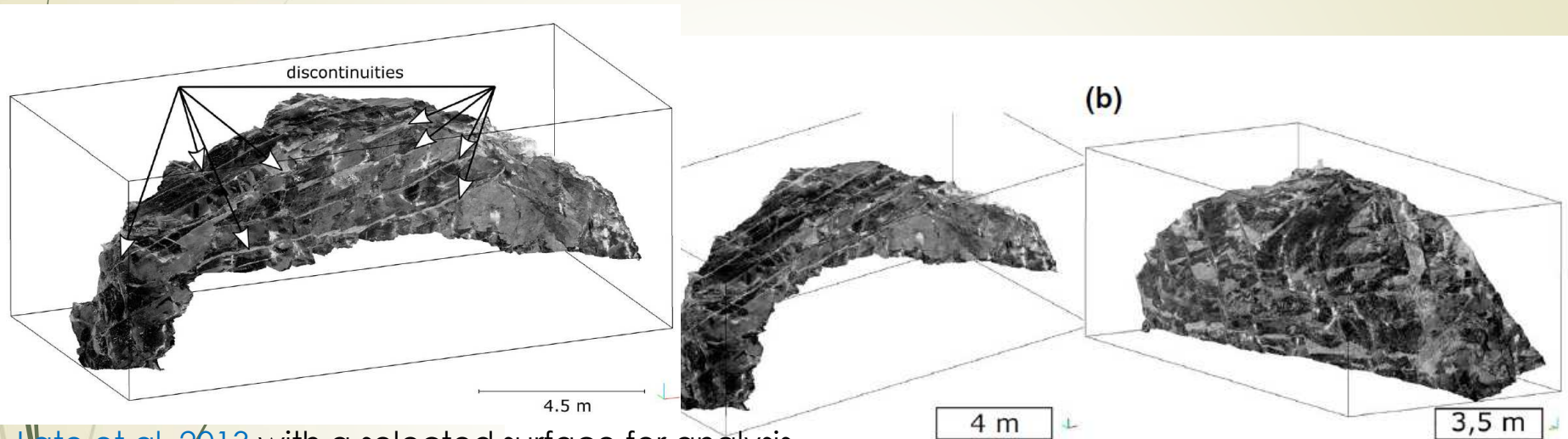


LMGC90 is a software dedicated to the modelling and the numerical simulation of dynamical problems made of large collections of rigid or deformable bodies interacting through interaction laws (Frictional Contact for example, etc.). **LMGC90** introduced and developed by J.J. Moreau (1988) and M. Jean (1999). **LMGC90** is Open-source software with its source code made available with a license in University Montpellier II, France.



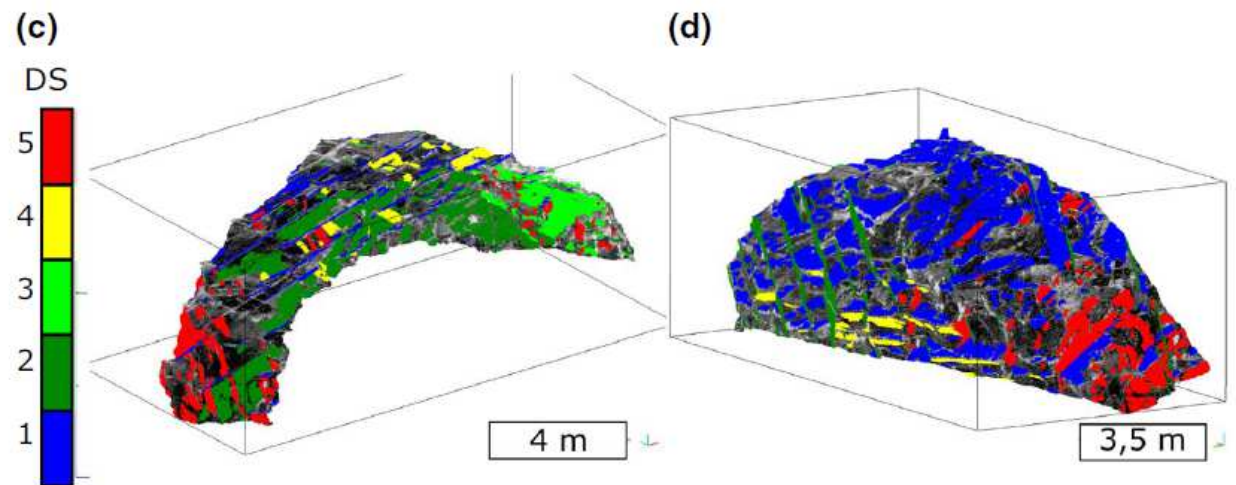
Two models exported from a scenario file in RESOBLOK (a) and LMG90 (b) three discontinuities sets using the colour signify: one colour/set

CASE STUDY



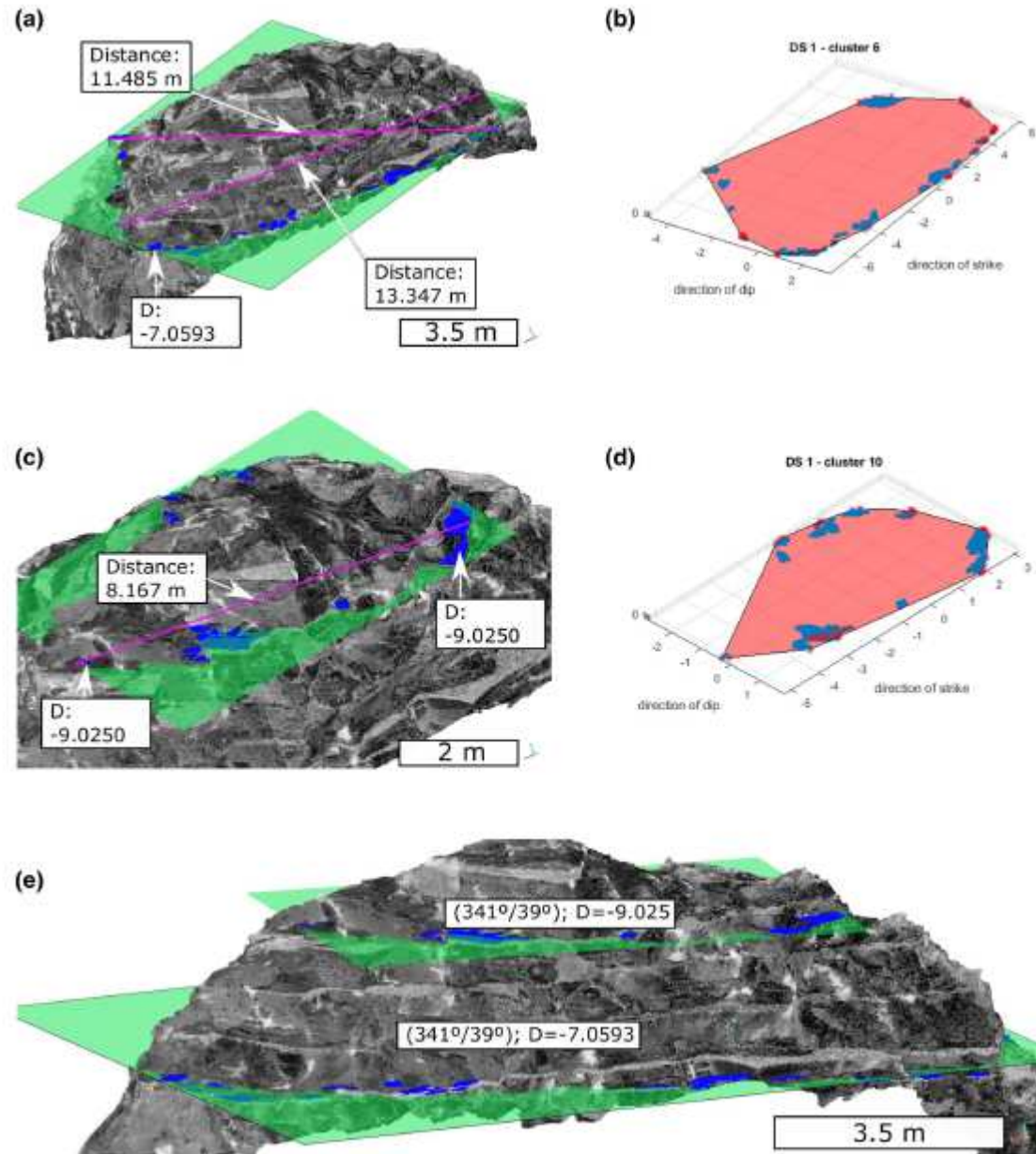
Lato et al. 2013 with a selected surface for analysis

The normal vector orientation of each point was calculated using 30 neighbours to enable higher convergence of the principal orientations (i.e., discontinuity set orientation)



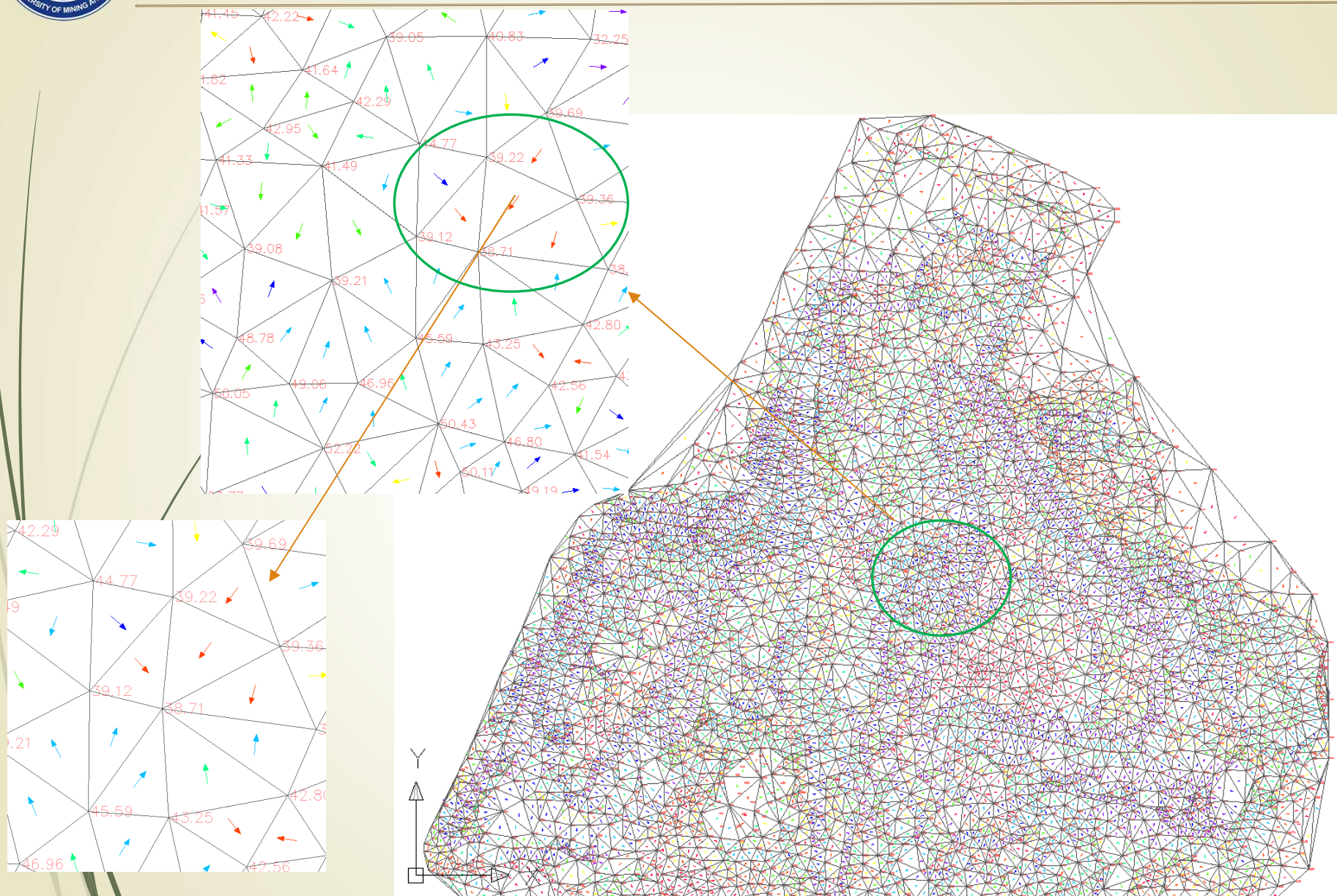


Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

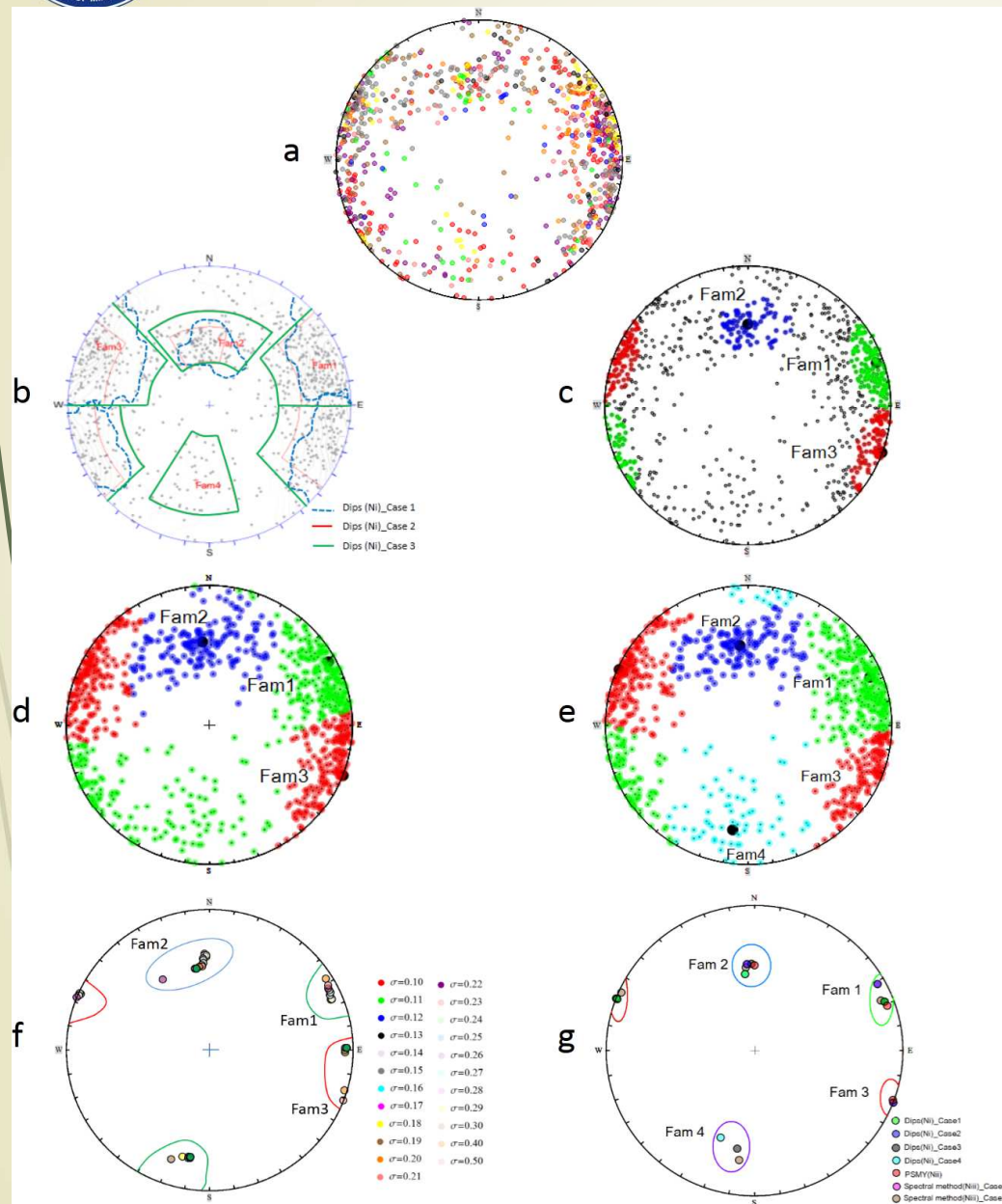




Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study



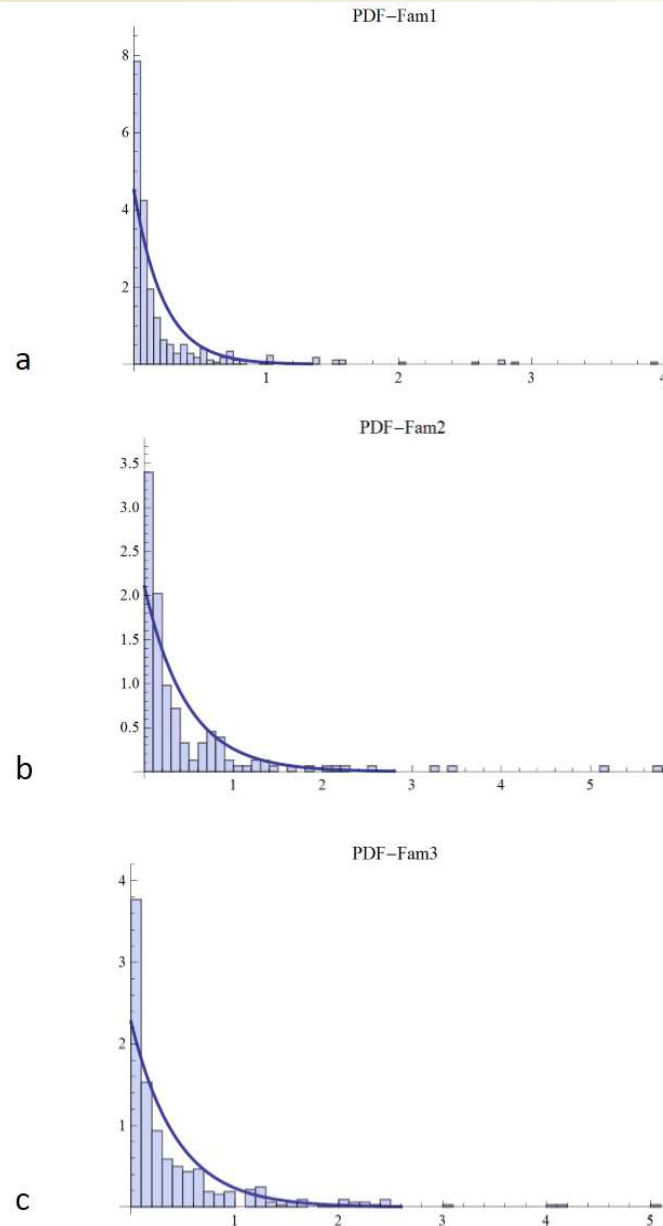
Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study



Stereographic projection of lower hemisphere Schmidt net: (a) plot of discontinuity data of the 11 scanlines (one color/scanline); (b) manual groupings in 3 and 4 main sets with DIPS method: Dips(Ni)_case1 with about 50% of the points belonging to no family (Gasc-Barbier et al. 2008); Dips(Ni)_case2 with about 41% of the points belonging to no family; and 15% of the points belonging to no family in Dips(Ni)_case3 with 4 main sets; (c) 3 main families using PSMY method; 47% of the points belonging to no family; (d) 3 main families with spectral method; (e) 4 main families (experimental) with spectral method; (f) comparison of the pole of sets according to the spectral method, the σ proposed value is 0.21 for these two cases; and (g) comparison of the various methods of grouping by the pole of sets. The PSMY and spectral methods were computed in Mathematica.



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study



From top to bottom: histogram and statistical adjustment, of the probability density curves of spacing for the 3 sets at Niii_cas1, family Fam1(a), Fam2(b) and Fam3(c) resp.

Methods and Parameters			Sets				
Dips (Ni)	Case 1 (3 Sets) (Gasc et al. 2008).	N_d	Fam1	Fam2	Fam3	Fam4	
		$N_{pc},\%$	242	35	151	/	
		α_d	28	4	18	/	
		β_d	50	/	/	/	
		K_r	249	173	111	/	
		λ	83	44	89	/	
		m	86	105	196.5	/	
		Spacing	0.13	0.12	0.14	/	
		λ	7.87	8.33	6.99	/	
		Hierarchic rules	Stop	Stop	Stop	/	
		N_d	224	72	211	/	
		$N_{pc},\%$	26.2	8.4	24.7	/	
	Case 2 (3 Sets)	α_d	59	/	/	/	
		β_d	249	171	289	/	
		λ	84	48	88	/	
		K_r	78.53	72.11	75.01	/	
		m	0.418	0.783	0.64	/	
		Spacing	2.39	1.275	1.554	/	
		λ	Stop	Stop	Stop	/	
		Hierarchic rules	Stop	Stop	Stop	/	
		N_d	274	123	291	40	
		$N_{pc},\%$	32	14	34	5	
		Case 3 (4 Sets)	α_d	249	178	111	10
			β_d	82	49	90	58
	K_r		39.69	28.35	26.66	27.865	
	m		0.348	0.468	0.494	0.248	
	Spacing		2.873	2.137	2.025	4.032	
	λ		Stop but F4	Stop but F4	Stop but F4	Infinite	
	Hierarchic rules		Stop but F4	Stop but F4	Stop but F4	Infinite	
	N_d		242	35	151	Measurements on outcrops	
	$N_{pc},\%$		28	4	18		
	α_d		249	173	111		21
	Case 4 (4 Sets) (Gasc et al. 2008).		β_d	83	44	89	54
			K_r	86	105	196.5	21.25
		m	4	2.5	3	2.5	
		Spacing	0.25	0.40	0.33	0.40	
		λ	Stop but F4	Stop but F4	Stop but F4	Infinite	
		Hierarchic rules	Stop but F4	Stop but F4	Stop but F4	Infinite	
		PSMY (Nii)	N_d	195	82	178	/
			$N_{pc},\%$	23	10	21	/
			α_d	53	/	/	/
			β_d	251	180	290	/
			λ	84	49	89	/
			K_r	96	50.67	98.10	/
	m		0.489	0.62	0.719	/	
Spacing	2.045		1.61	1.392	/		
λ	0.489		0.62	0.719	/		
Hierarchic rules	2.045		1.61	1.392	/		
Spacing	Stop		Stop	Stop	/		
Hierarchic rules	Stop		Stop	Stop	/		
Spectral method (Niii)	Case 1 (3 Sets)	N_d	360	164	332	/	
		$N_{pc},\%$	42	19	39	/	
		α_d	100	/	/	/	
		β_d	241	175	291	/	
		λ	84	50	90	/	
		K_r	15.76	17.17	32.08	/	
		m	0.222	0.475	0.439	/	
		Spacing	4.504	2.104	2.274	/	
		λ	4.504	2.104	2.274	/	
		Hierarchic rules	Stop	Stop	Stop	/	
		N_d	331	146	304	75	
		$N_{pc},\%$	39	17	35	9	
	Case 2 (4 Sets)	α_d	100	/	/	/	
		β_d	248	175	114	9	
		λ	80	49	88	63	
		K_r	29.16	19.88	31.81	11.428	
		m	0.269	0.456	0.484	0.582	
		Spacing	3.71	2.194	2.066	1.718	
Case 2 (4 Sets)	λ	3.71	2.194	2.066	1.718		
	Hierarchic rules	Stop but F4	Stop but F4	Stop but F4	Infinite		



CONCLUSIONS

- The three grouping methods were applied to a rock cut "Case study" and the statistical parameters of the families were computed from 856 measured discontinuities from "Automatic Mapping of Rock Mass Joints Using UAV Technology".
- Three grouping methods of discontinuities into main sets were presented. Each method has its advantage. PSMY allows determining automatically the optimal number of families to be adopted, but a proportion of discontinuities belongs to no families (47% in the application case). The spectral method attributed each discontinuity to a family but the number of families has to be given (possibly from the previous PSMY method) and the grouping depends on a factor σ whose sensitivity was investigated in the present study. The "manual" method using DIPS software is convenient and useful; it can allow taking into account qualitative and geological information on data, but it is broadly dependent on the user's skills and experience comprehension, and can give variables results.



Automatic Mapping of Rock Mass Joints Using UAV Technology: Case Study

Thank you for your attention!

NGUYEN Anh Tuan, PHAM Van Viet
Hanoi University of Mining and Geology, Vietnam
Email: nguyenanhtuan@humg.edu.vn

